Response of Corals to Changes In Solar Radiation and Temperature

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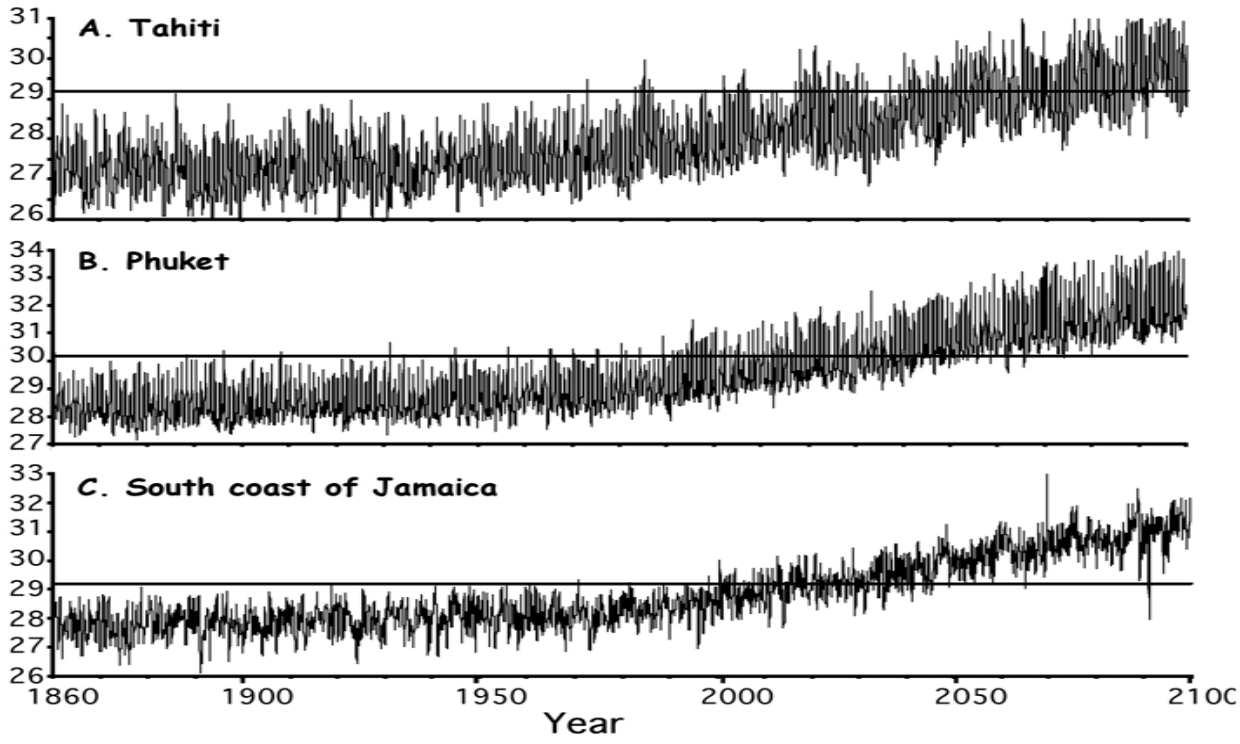
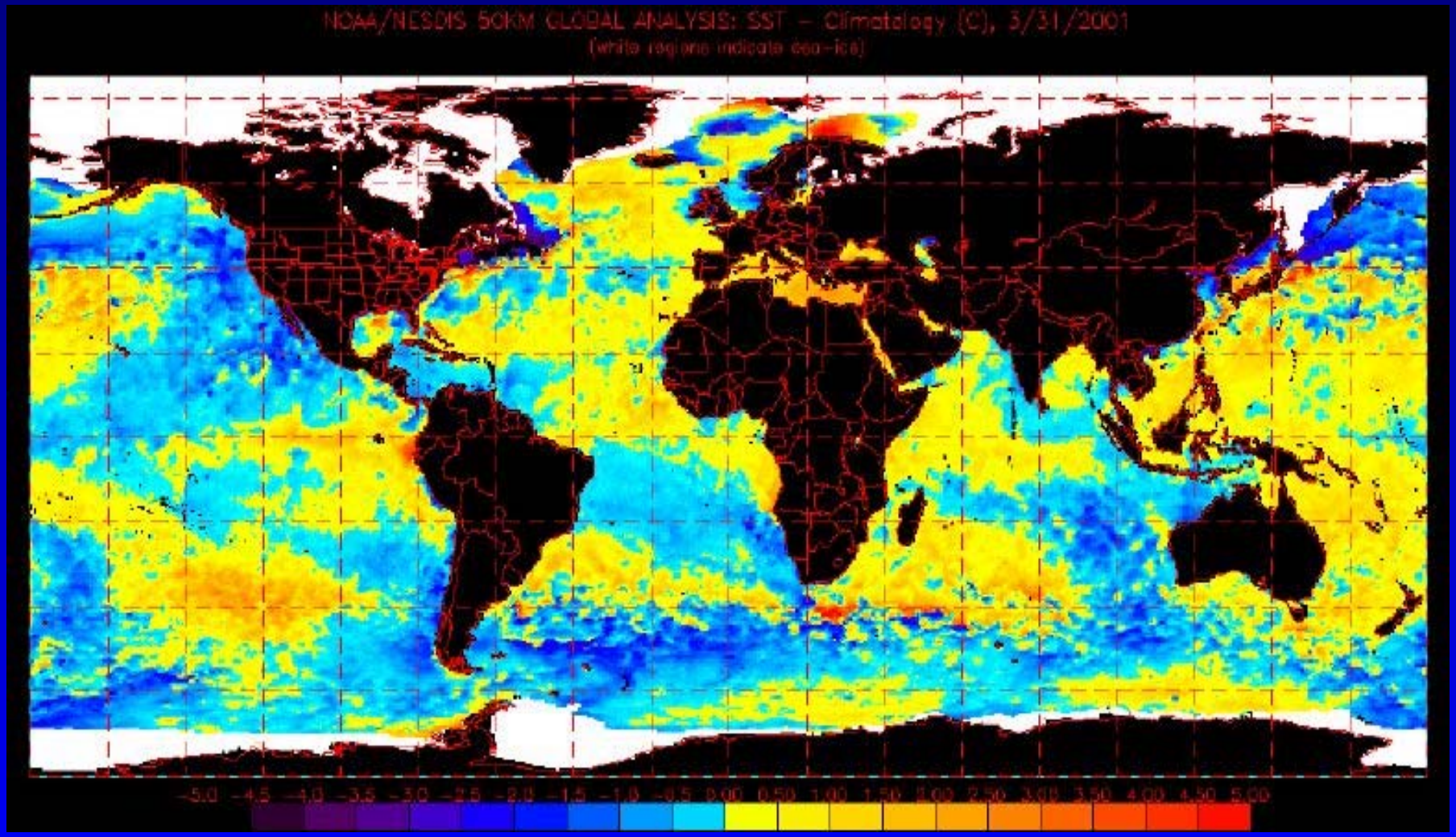
It's Getting Warmer-End of Discussion!



Hoegh-Guldberg 1999 (*Mar. Freshwater Res.*, 50:839-866)

NOAA "Hot Spot" Data

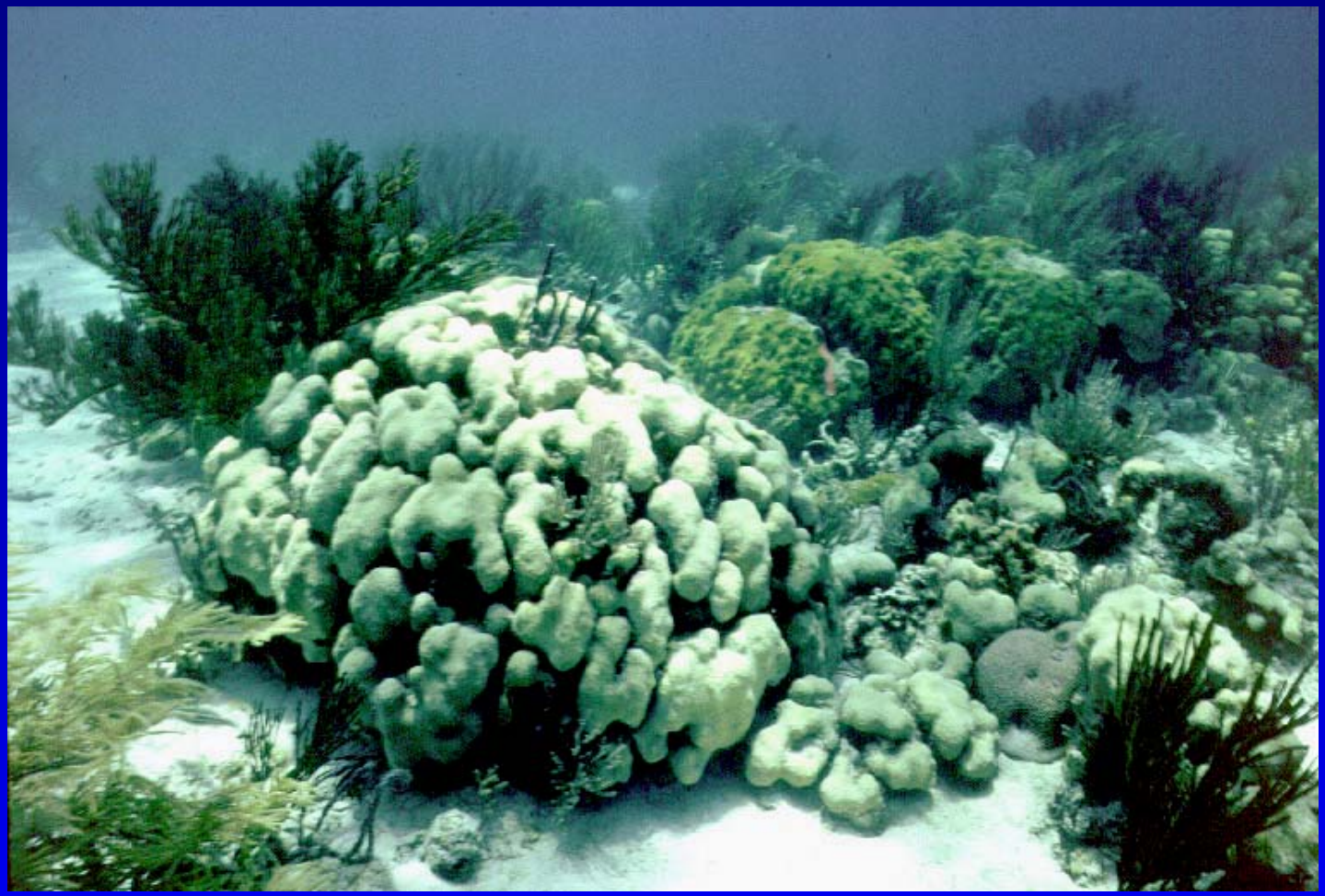


Coral Bleaching

It is generally believed that corals live near their upper thermal limit and exceeding that “set-point” results in bleaching.

What is bleaching?
Catastrophic expulsion of zooxanthellae in response to environmental stress.

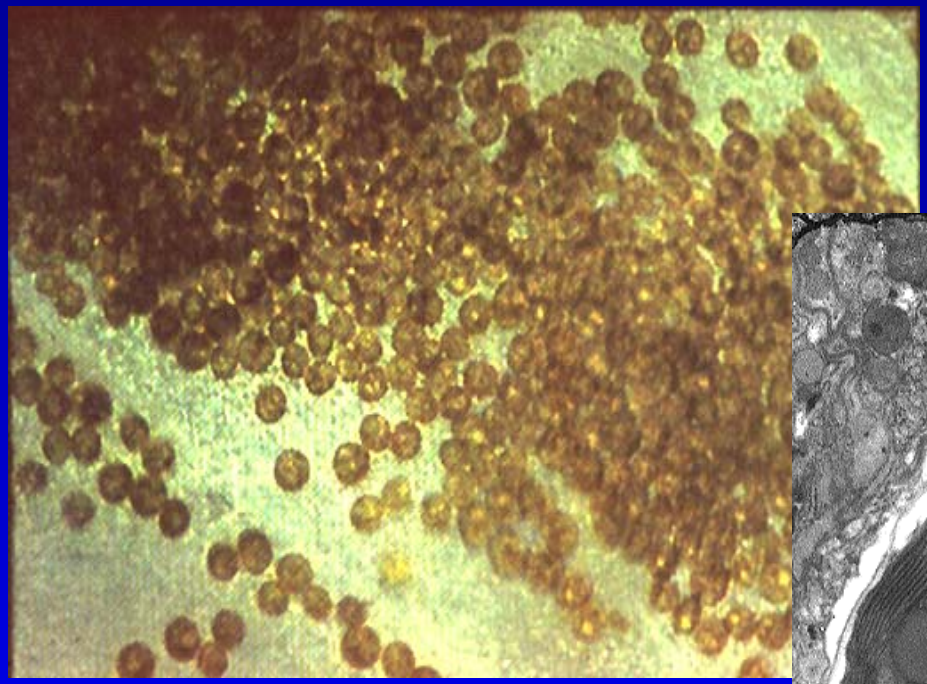
Results-Unprecedented Number of Coral Bleaching Events Since 1980's

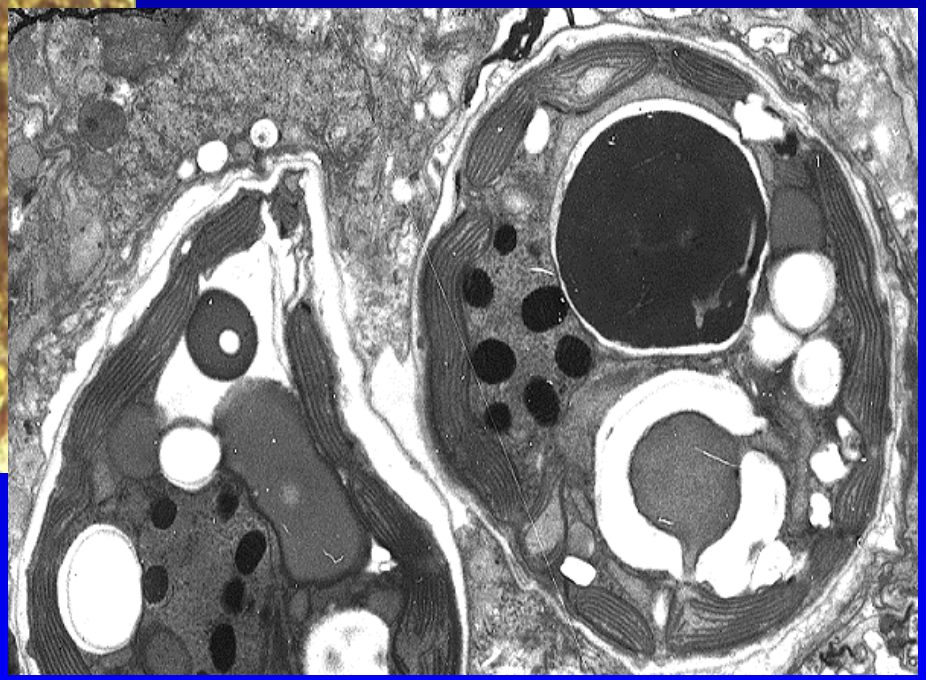


Coral Reefs In Decline

In hospite Environment?

Is there something about the environment *in hospite* that affects organismal performance?





In hospite Environment

What we think we know-sink limitations……

N-limited

-Oligotrophic waters

-Limited *in hospite* supplies

-Regulates growth rates

-N-limitation could affect turnover rate of critical proteins in electron transport and PSII

C-limited

Delivery vs. availability

Isotope work (Muscatine et al. 1989)

Flow effects on DBL and biochemical plasticity (Weis et al. 1989, Lesser et al. 1994)

Hyperoxic Environment

Can be x 4 or greater than ambient (Dykens and Shick 1982)

Type II Rubisco and C_2 pathways (Photorespiration)

Mehler-Ascorbate-Peroxidase (MAP) cycle another electron sink

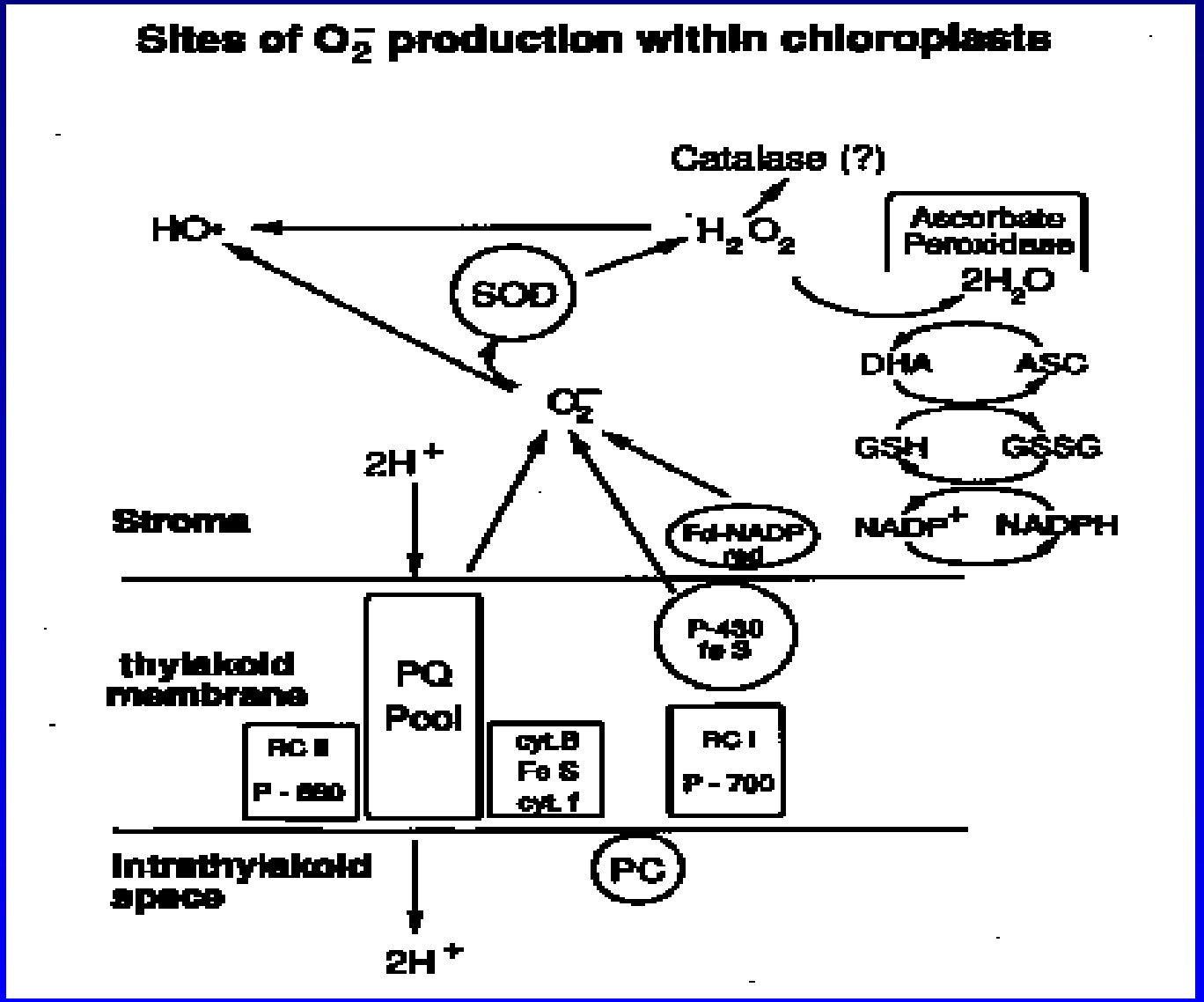
***Fe-limited*?**

Light Environment

Attenuation/absorption

Scattering

Hyperoxic Environment



Consequences of Hyperoxic Environment

Light-dependent production of superoxide radicals (Mehler reaction) is the result of photosensitization reactions during exposure to either PAR or UVR in the presence of chlorophyll and oxygen. The production of superoxide radicals is also linearly proportional to the concentration of oxygen. What are the targets of reactive oxygen species (ROS)?

DNA-well known source of DNA strand breaks especially hydrogen peroxide with its neutral charge and permeability through membranes.

Lipids-lipid peroxidation of membranes especially during exposure to elevated temperatures and phase transitions (gel-fluid state) of membranes. Membrane stability effects protein function and permeability of charged molecules.

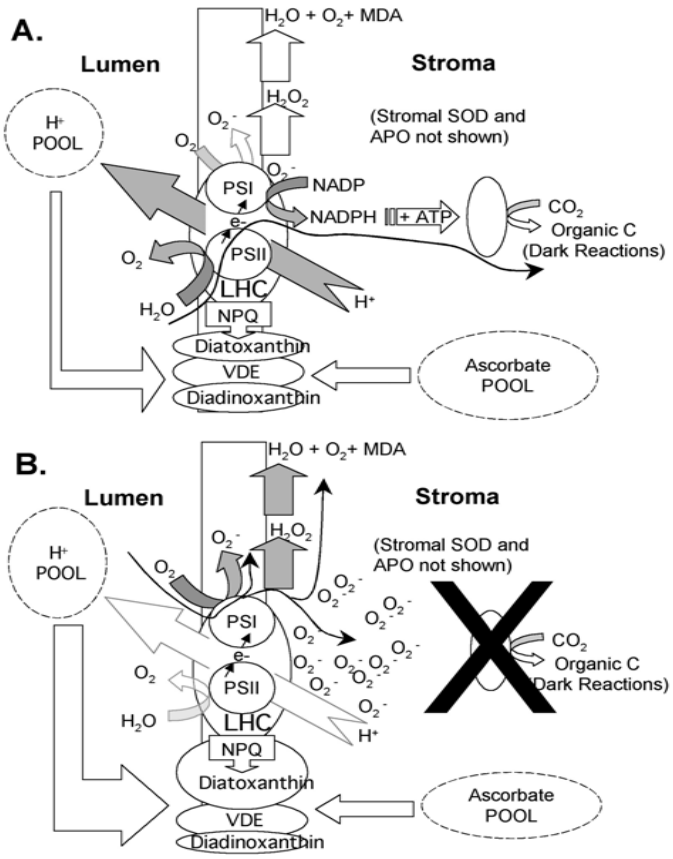
Proteins-D1 protein of PSII, Rubisco is known to be sensitive to hydrogen peroxide as is SOD.

Coral Stress/Bleaching Bioindicators

What are the potential indicatorsw of damage in corals during exposure to elevated temperatures and PAR/UVR?

-Increase in respiration relative to photosynthesis that decreases P/R ratio and potentially amount of translocated photosynthate
-Decrease in mycosporine-like amino acids (MAAs)
-Membrane instability through phase transitions of membrane lipids, especially in thylakoid membranes
-Increased production of ROS in mitochondria and chloroplasts
-Damage to D1 protein
-Damage to DNA
-Impairment of PSII function
-Damage to Rubisco and/or Rubisco activase
-Photoinhibition of photosynthesis in zooxanthellae and synergism with PAR/UVR
-Apoptosis in host cells and zooxanthellae

Temperature Stress and Coral Bleaching



Jones et al. 1998, PCE, 21:1219-1230

Photoinhibition model of bleaching based on sink limitation

My thoughts-

-Corals do have an effective mechanism to avoid photoinhibition under "normal" conditions-NPQ

-Corals are chronically under sink-limitation and sink-limitation decreases point at which light or elevated T°C causes photoinhibition

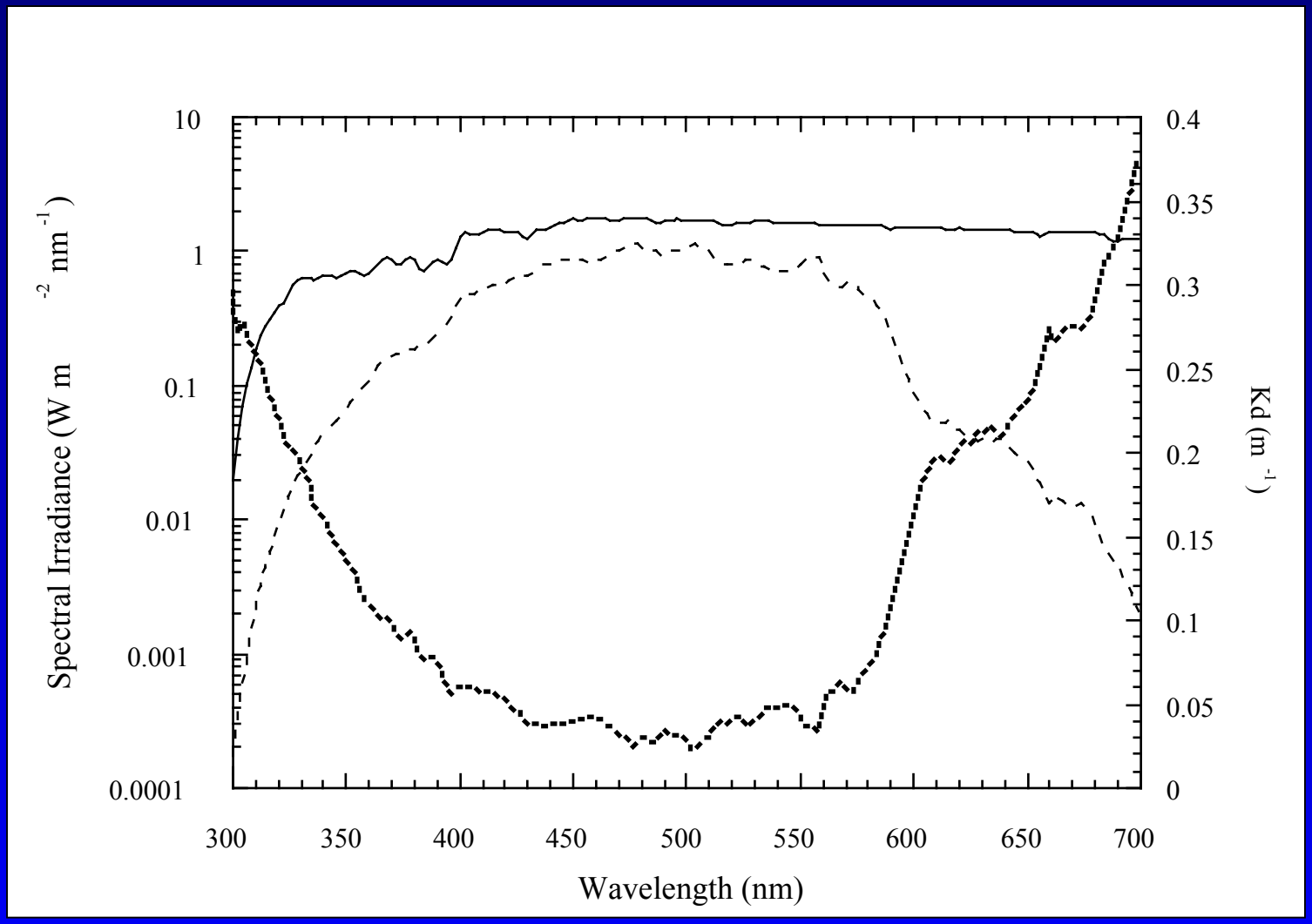
-Corals are chronically exposed to oxidative stress and UVR decreasing Rubisco acitivities

-Corals are at their upper thermal limits

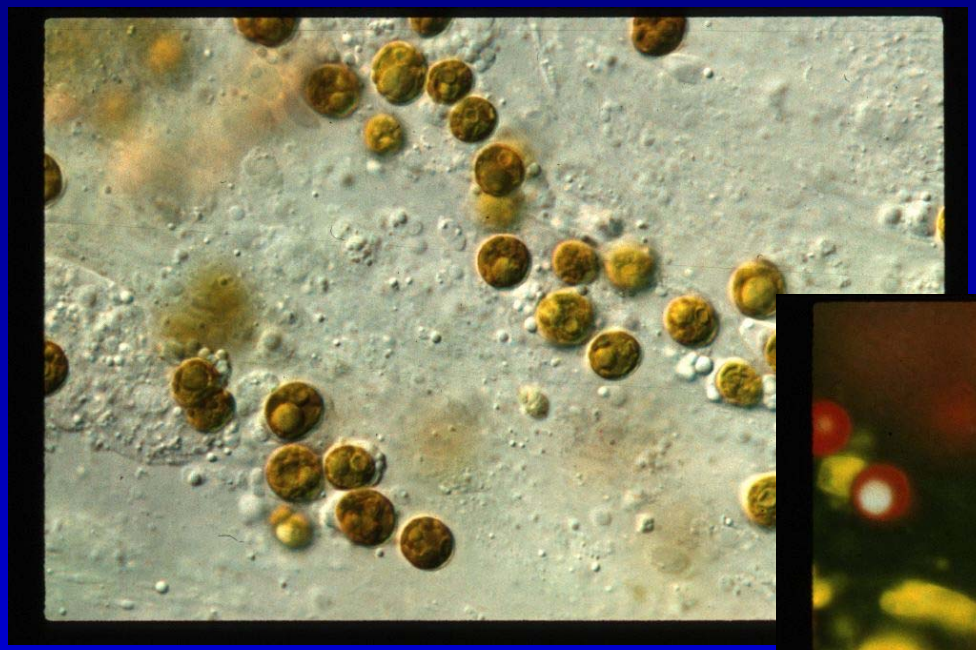
-During exposure to elevated temperatures PSII dysfunction does occur

-Exposure to PAR/UVR does the rest

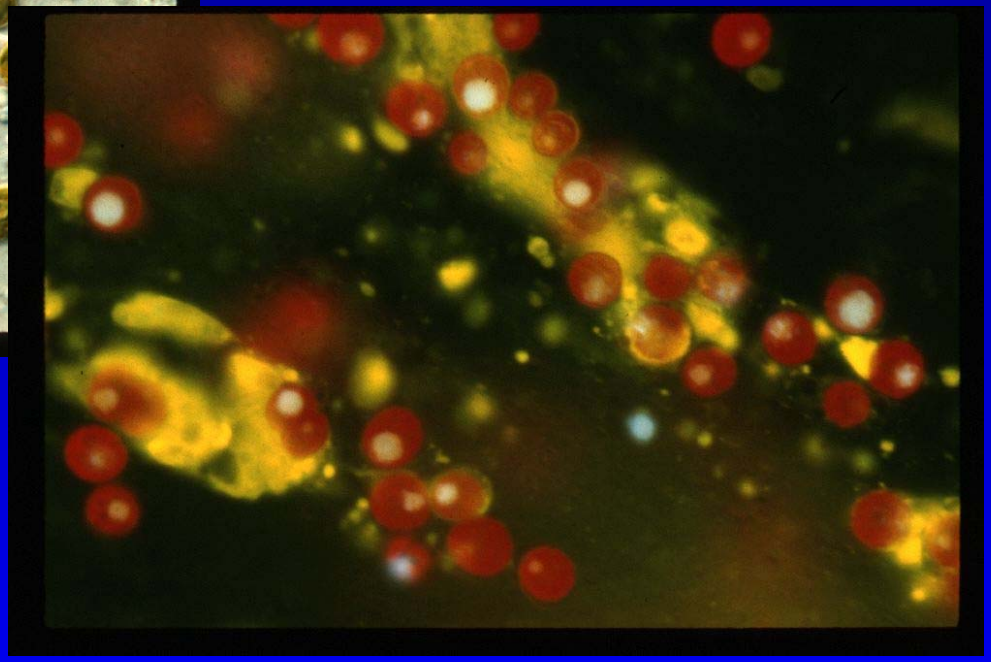
Plenty UVR/PAR Available (Case 1 Waters)



New Tools for Coral Biologists-Active Fluorescence

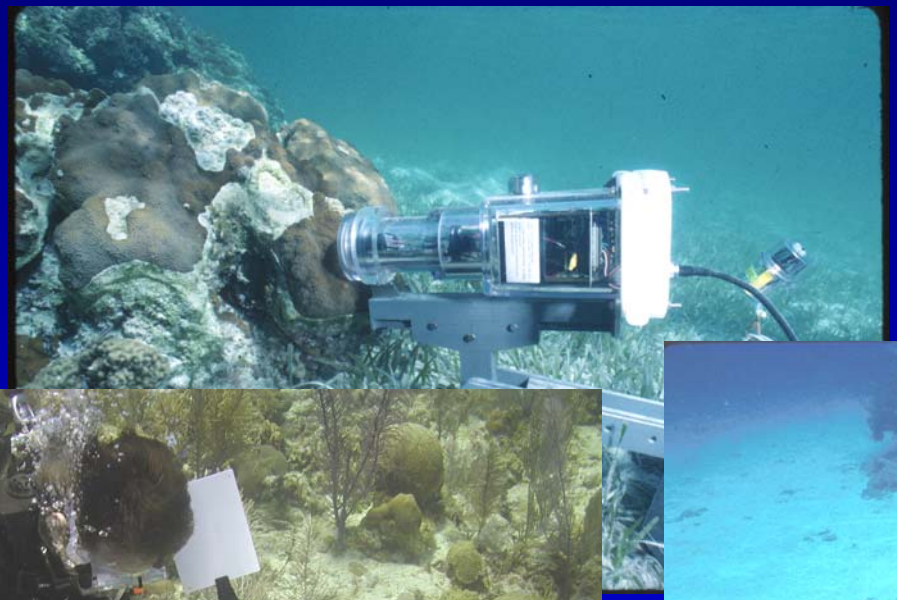


PAM-Pulse amplitude modulated or saturation pulse technique (multiple photochemical turnover)

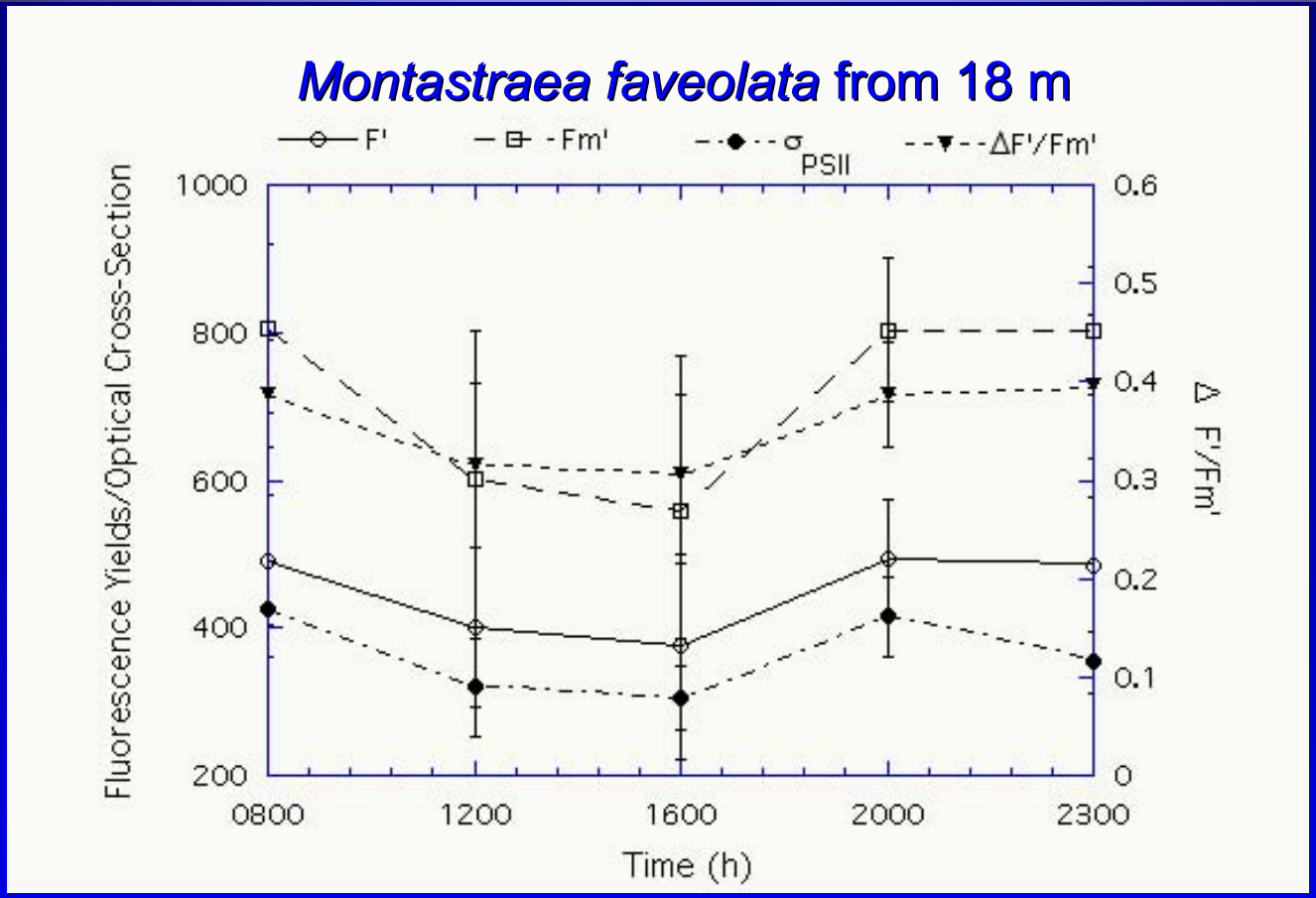


FRRF-Fast repetition rate fluorometer (single photochemical turnover)

FRR and PAM Fluorometers

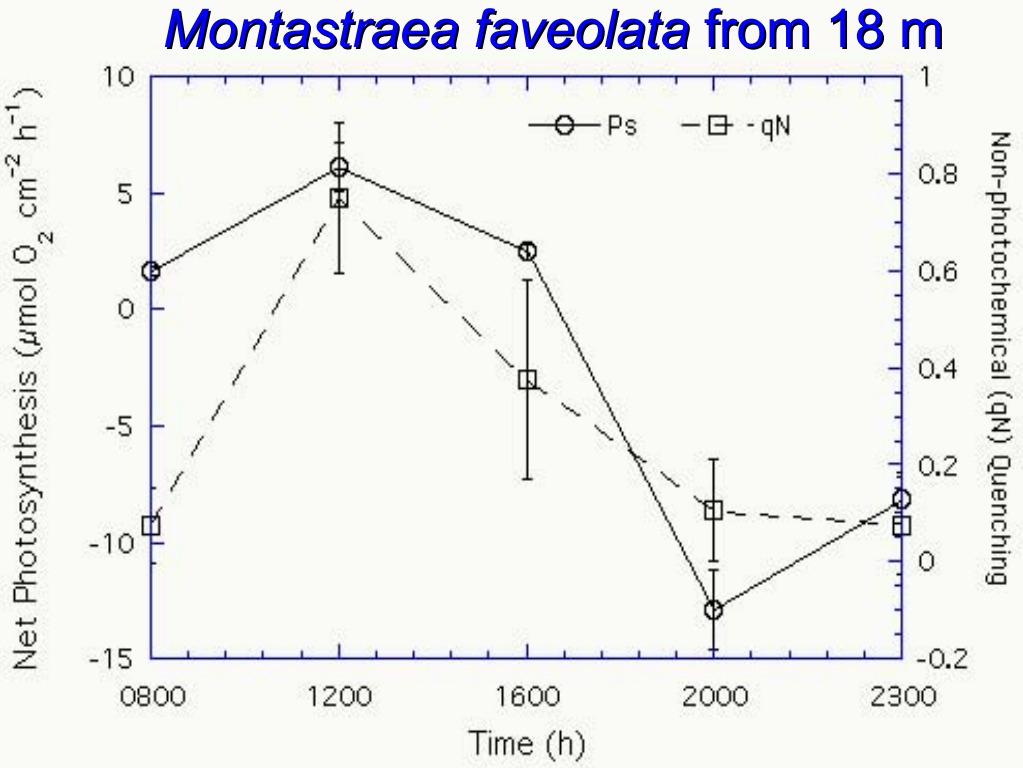


Diurnal Changes In the QuantumYield of Fluorescence for PSII



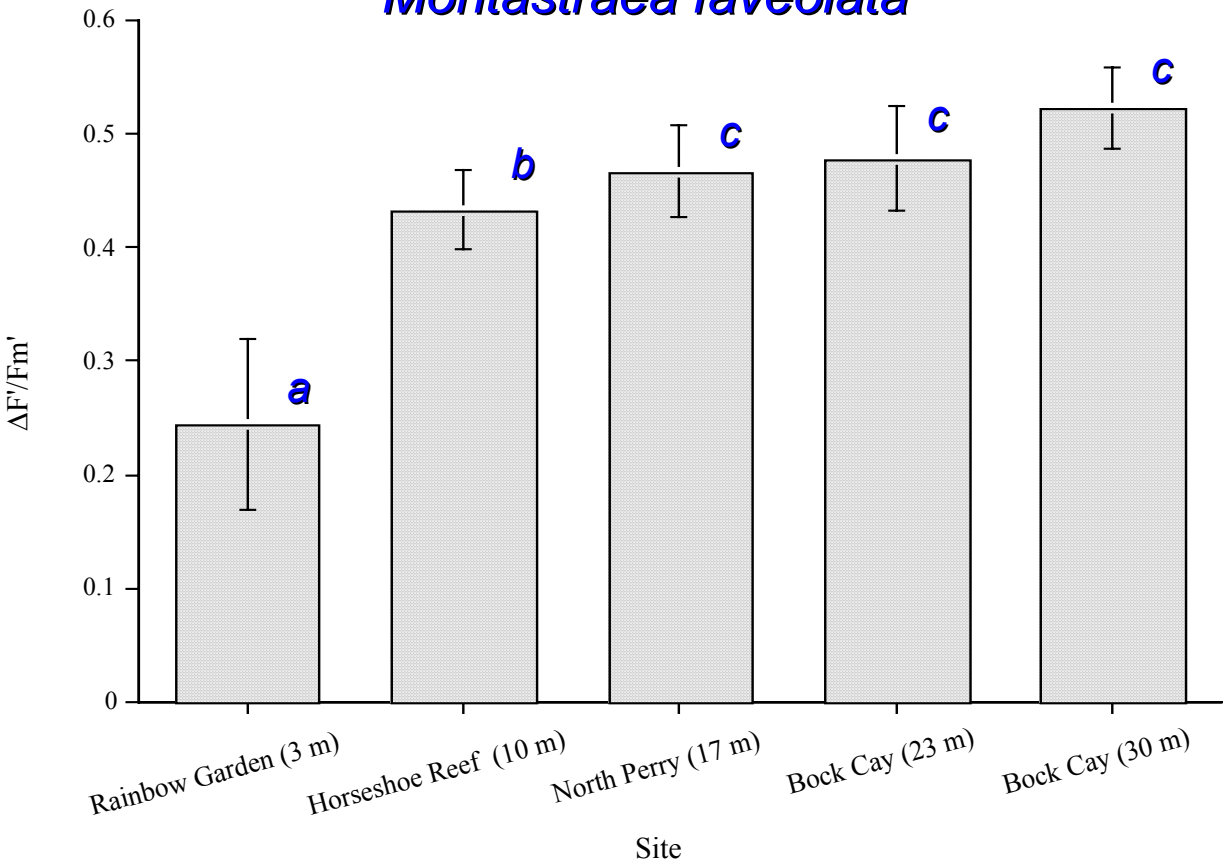
Hoegh-Guldberg and Jones 1999 (*MEPS*, 183:73-86)
Brown et al. 1999 (*Coral Reefs*, 18:99-105)
Lesser and Gorbunov 2001 (*MEPS*, 212:69-77)
Gorbunov et al. 2001 (*L&O*, 46:75-85)

Relationship Between NPQ and Photosynthesis



Lesser and Gorbunov 2001 (*MEPS*, 212:69-77)
Also, $\Delta F/F_m$ ' inversely correlated with irradiance
while photosynthesis directly correlated with irradiance.
See also Hoegh-Guldberg and Jones (1999) for similar results.

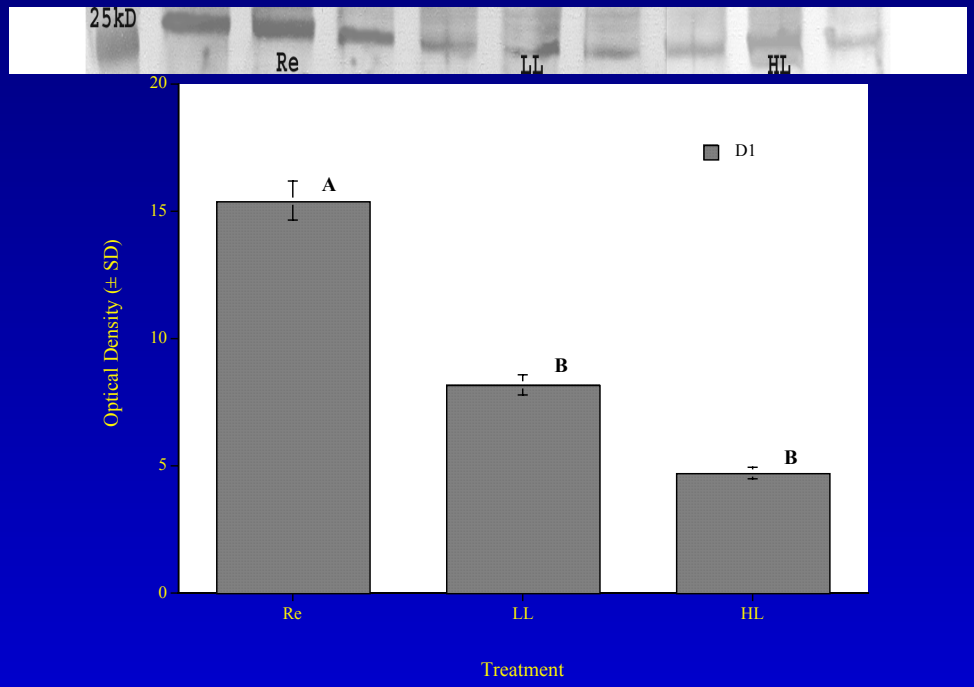
Relationship Between Quantum Yield and Depth



Lesser and Gorbunov 2001 (*MEPS*, 212:69-77) Changes in Fv/Fm correlated with increasing depth or decreasing irradiance. Bathymetric increase in efficiency and decrease in irradiance leads to decrease in productivity with depth

Chronic Photoinhibition and D1 Damage

Warner et al. 1999, *PNAS*, 96:8007-8012
Relative D1 content in *Montastraea annularis* zooxanthellae after 48 h exposure to elevated temperature (lower) compared to controls (higher) using immunoblots

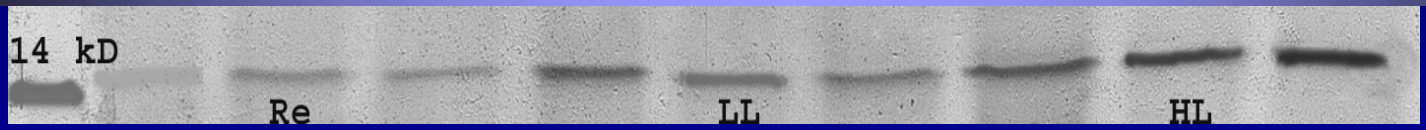


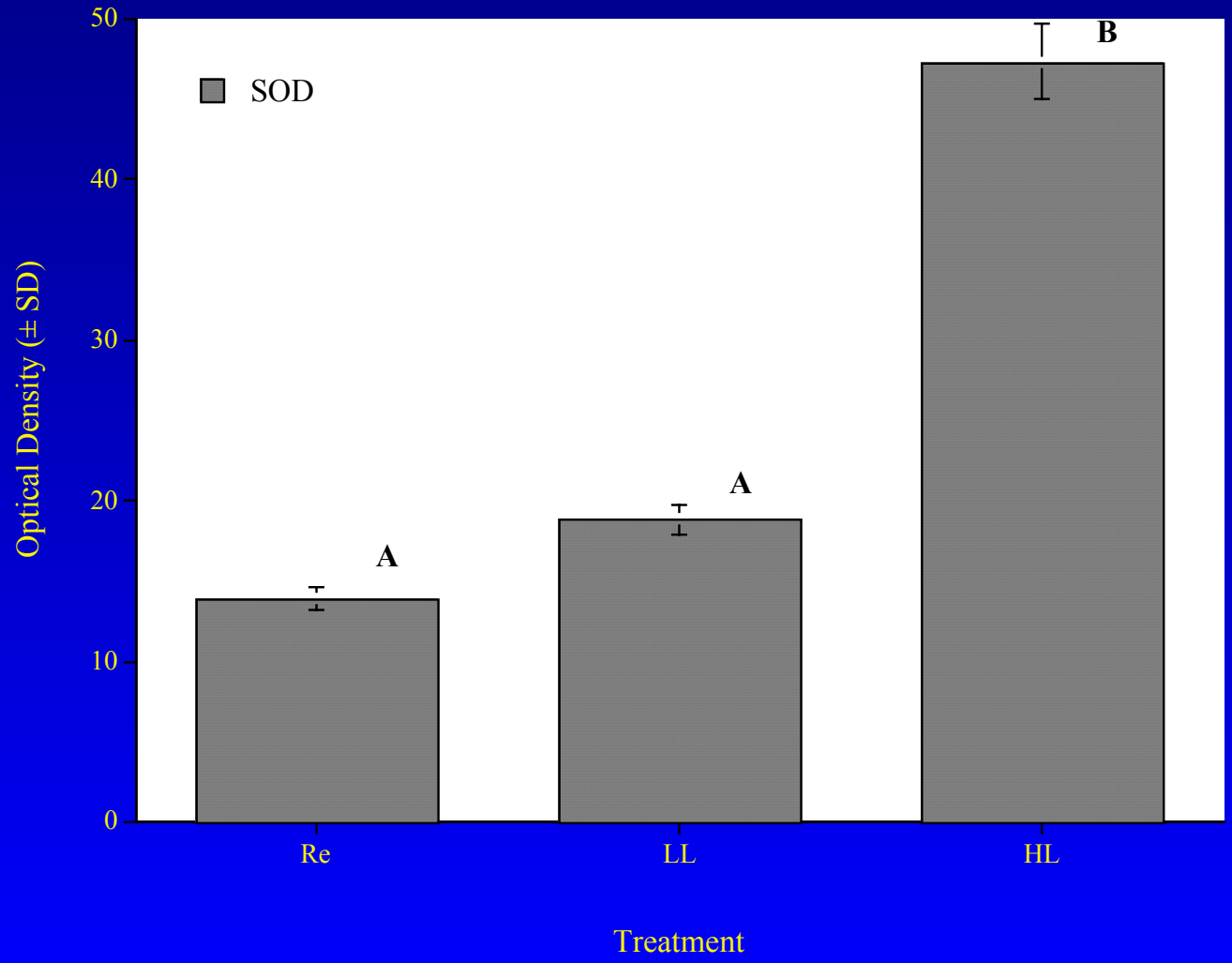
Lesser, unpublished bleaching study on *Montastraea faveolata* zooxanthellae
Similar results to Warner plus showed bands at ~64KD or D1/D2 heterodimer

D1/D2 heterodimer

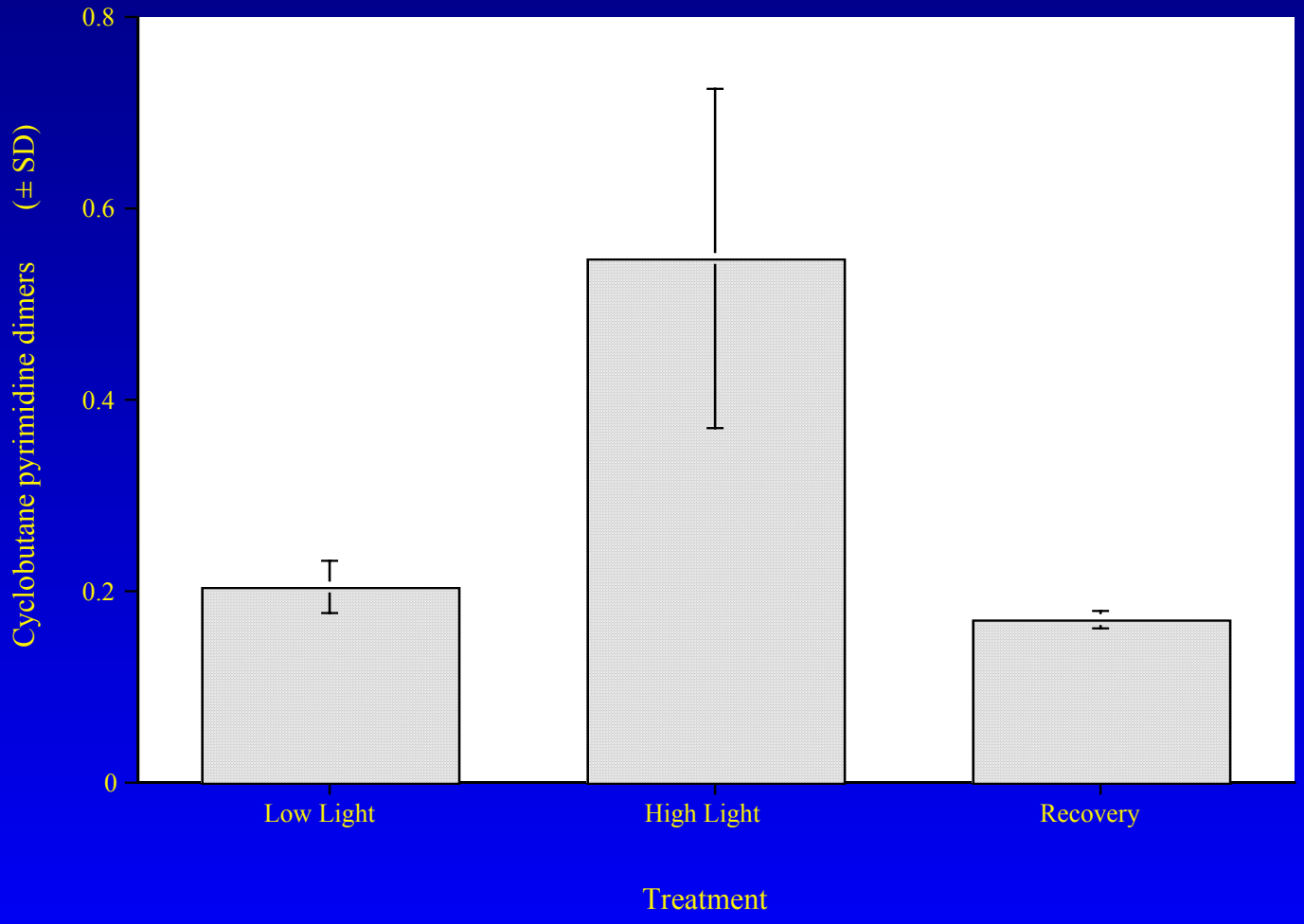
D1/D2 heterodimer is seen under photoinhibitory conditions, especially HL and elevated temperatures

Superoxide Dismutase

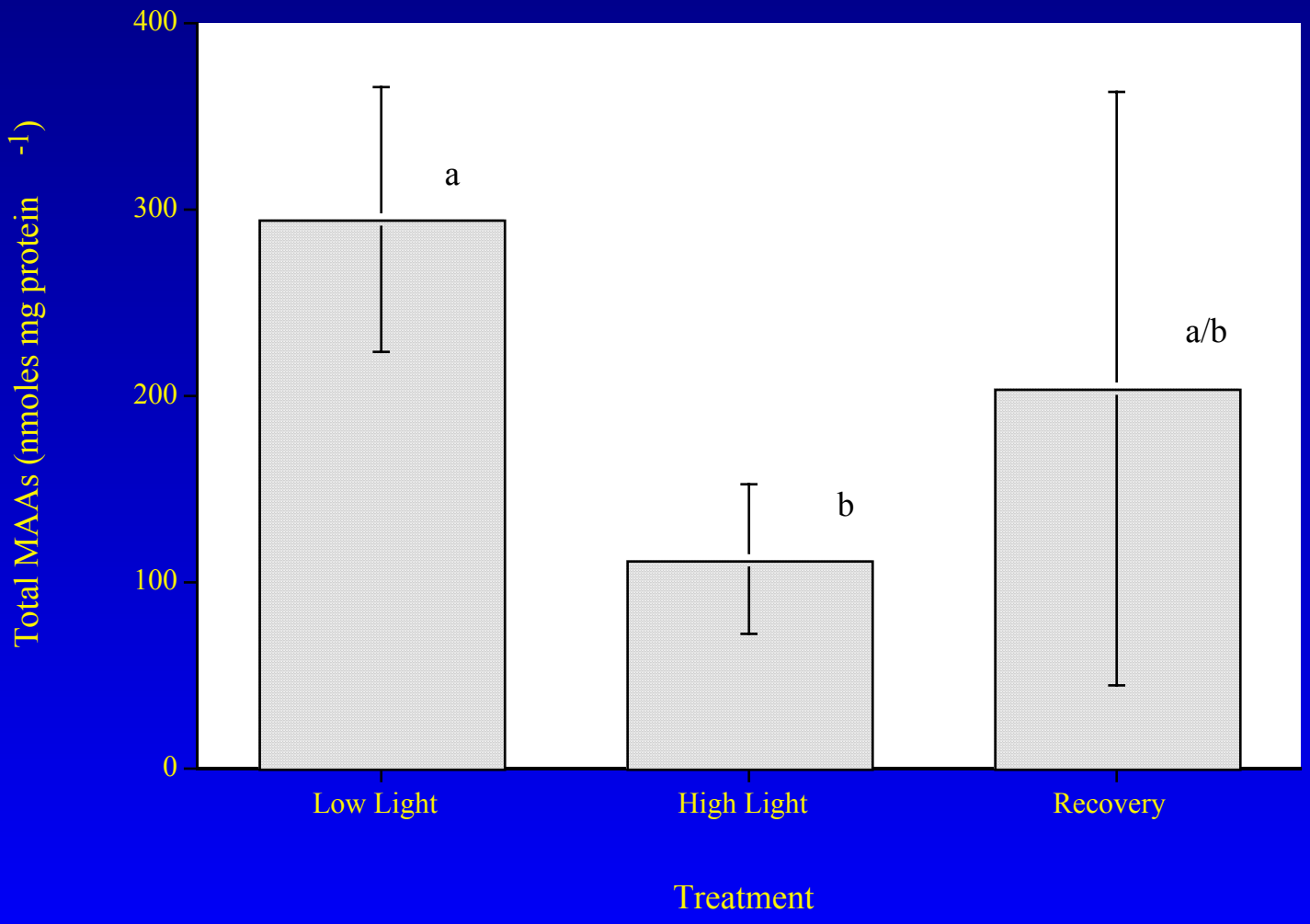




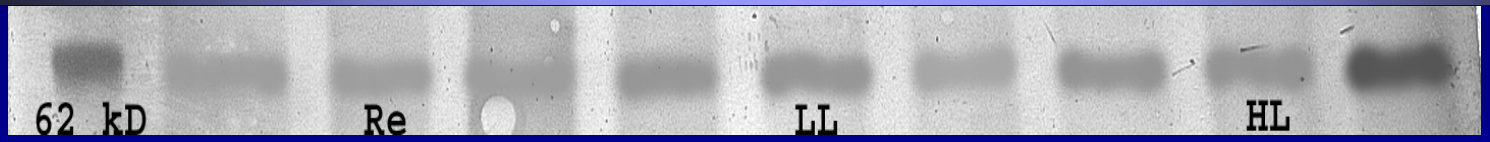
DNA Damage-Cyclobutane Pyrimidine Dimers

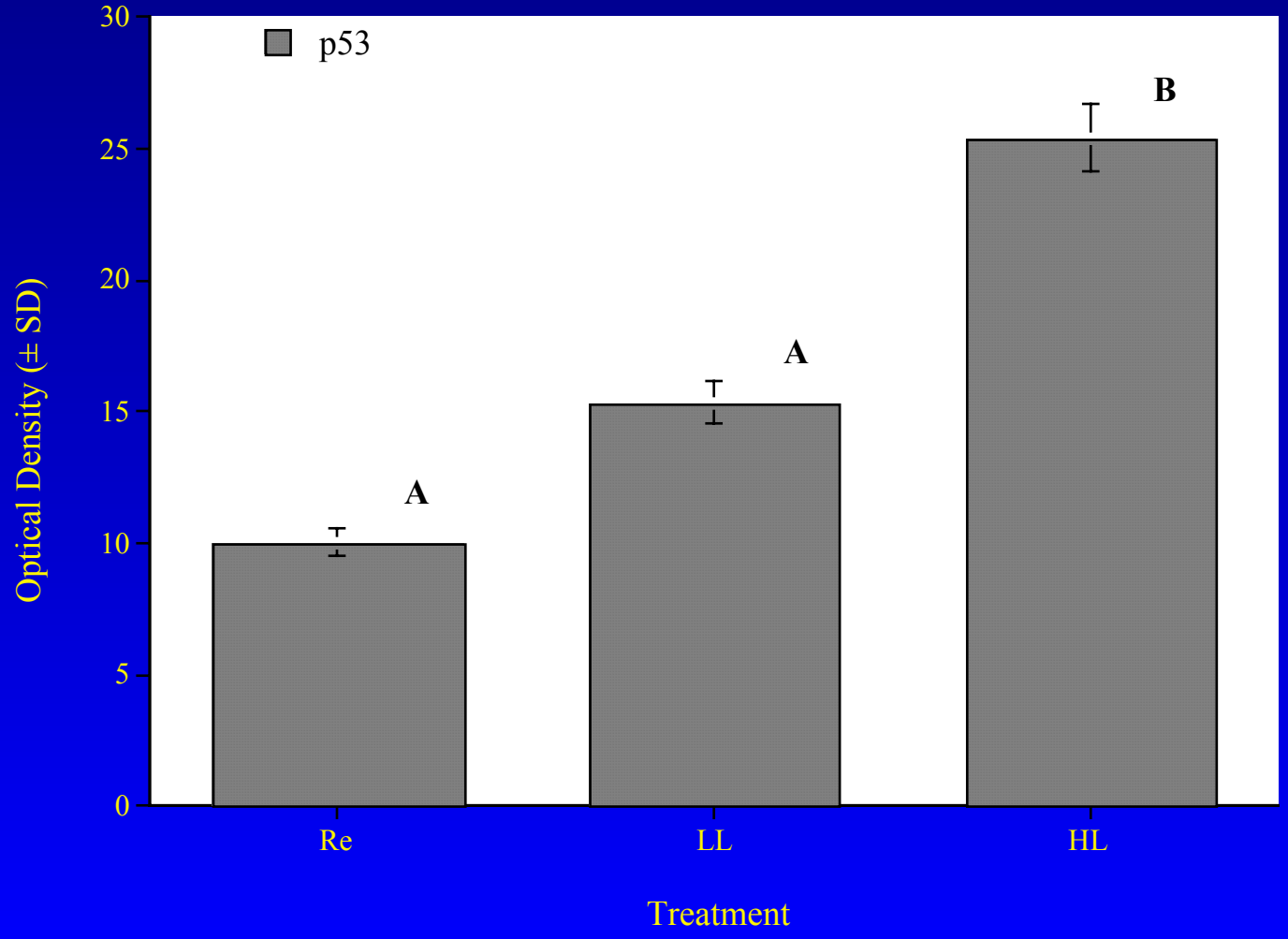


Mycosporine-like Amino Acids

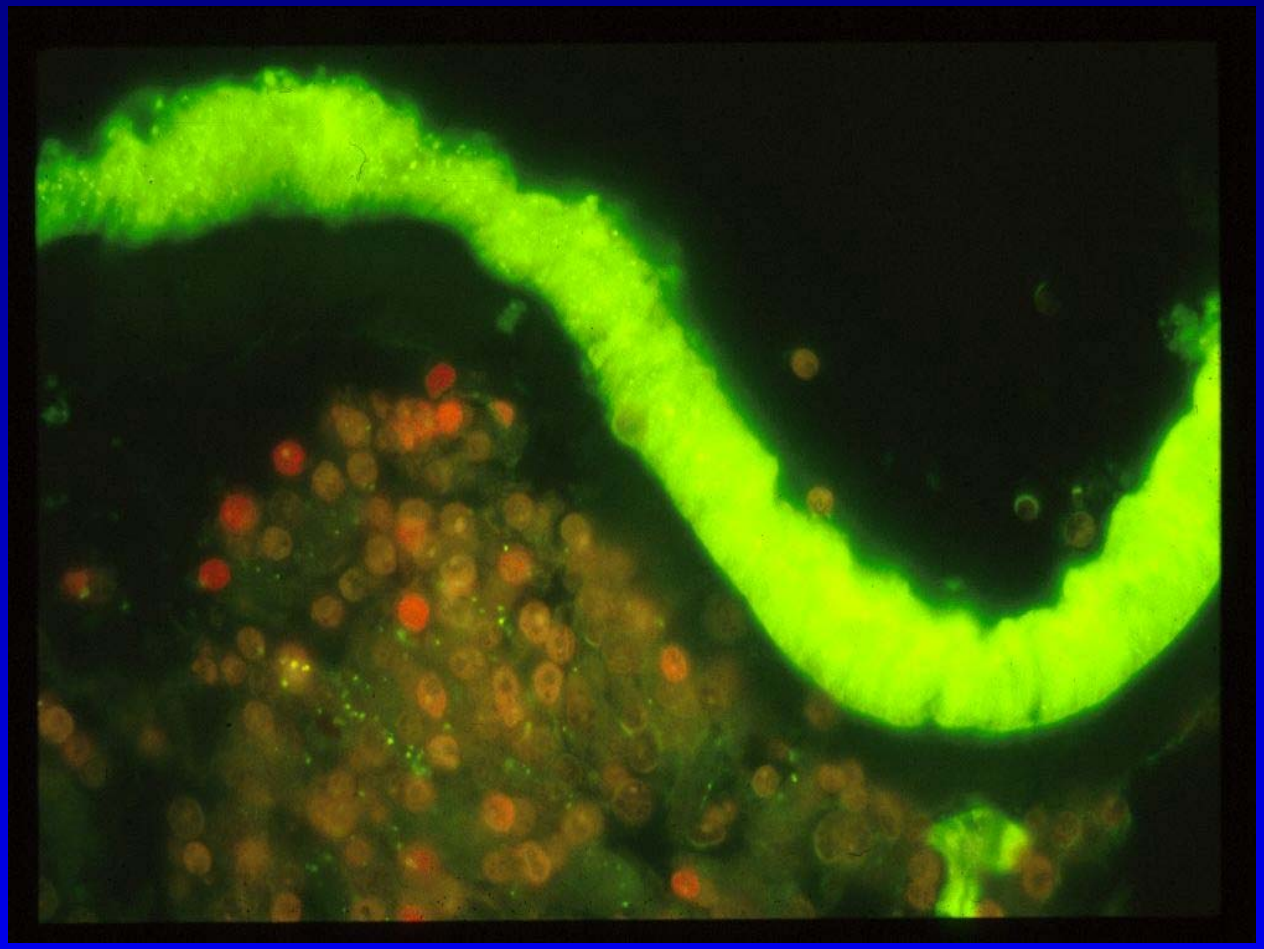


*p*53-A G1/S Cellular Gatekeeper

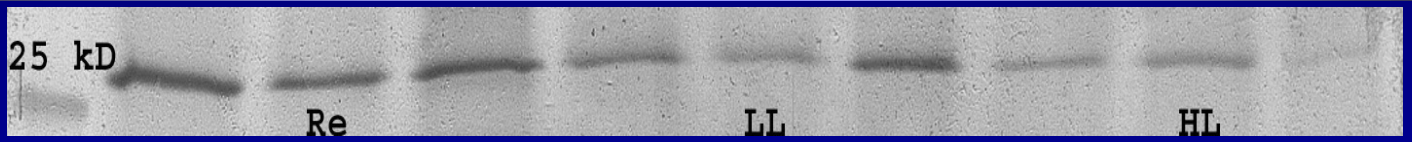


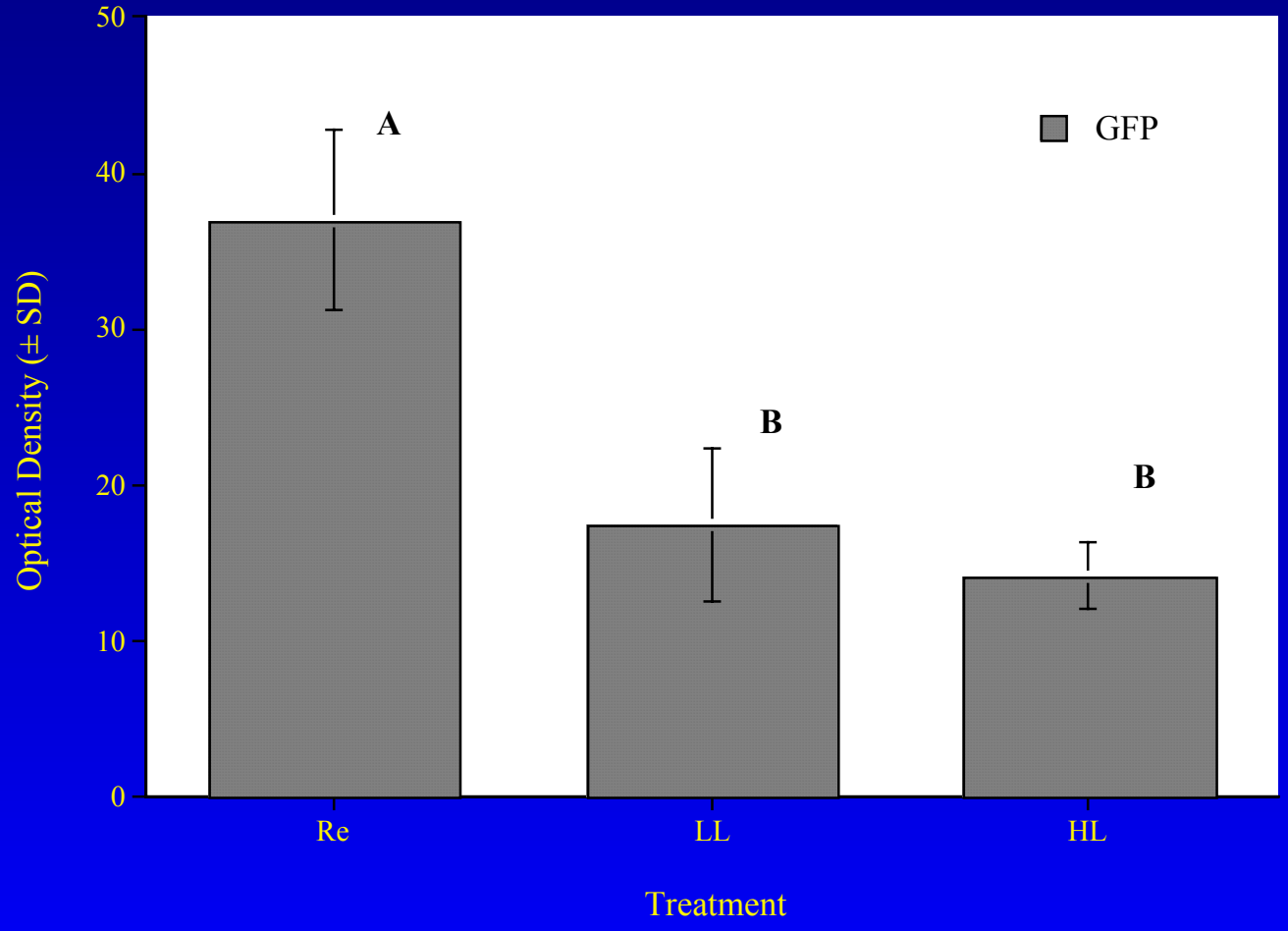


Host Fluorescent Proteins



Green Fluorescent Proteins





The Future- Multi-Level Approach

Remote Sensing-SST and Coral Reef Mapping

Real Time Data Collection From Buoys-Weather Station, SST, E_d, E_u, L_u, R_{rs}, IOP's, Currents

In-water Temperature Thermistors-Cheap, reliable, and easy to deploy. Systematic coverage of many reefs and within reef bathymetric data.

Fluorescence-PAM or FRRF techniques to monitor reefs regularly and when indications suggest to monitor susceptible species continuously.

Molecular or Biochemical Indicators-D1 protein of PSII, HSP's, SOD, microarrays, We Need Mutants!

After Bleaching Event-Rapid assessment. Combine remote sensing with AGRA-like protocols

Blank

Hyperoxic Environment

$O_2 + e^- \rightarrow O_2^-$ (1)

$2O_2^- + 2H^+ \rightarrow H_2O_2 + O_2$ (2)

$H_2O_2 + Fe^{2+} + H^+ \rightarrow OH^\cdot + Fe^{3+} + H_2O$ (3)

Fenton reaction with transition metals (e.g. Cu)

$Fe^{3+} + O_2^- \rightarrow Fe^{2+} + O_2$ (4)

Metal catalyzed Haber-Weis Cycle which regenerates Fe^{2+} for Equation (3)

Fe catalyzed

(net) $O_2^- + H_2O_2 \rightarrow O_2 + OH^- + HO^\cdot$

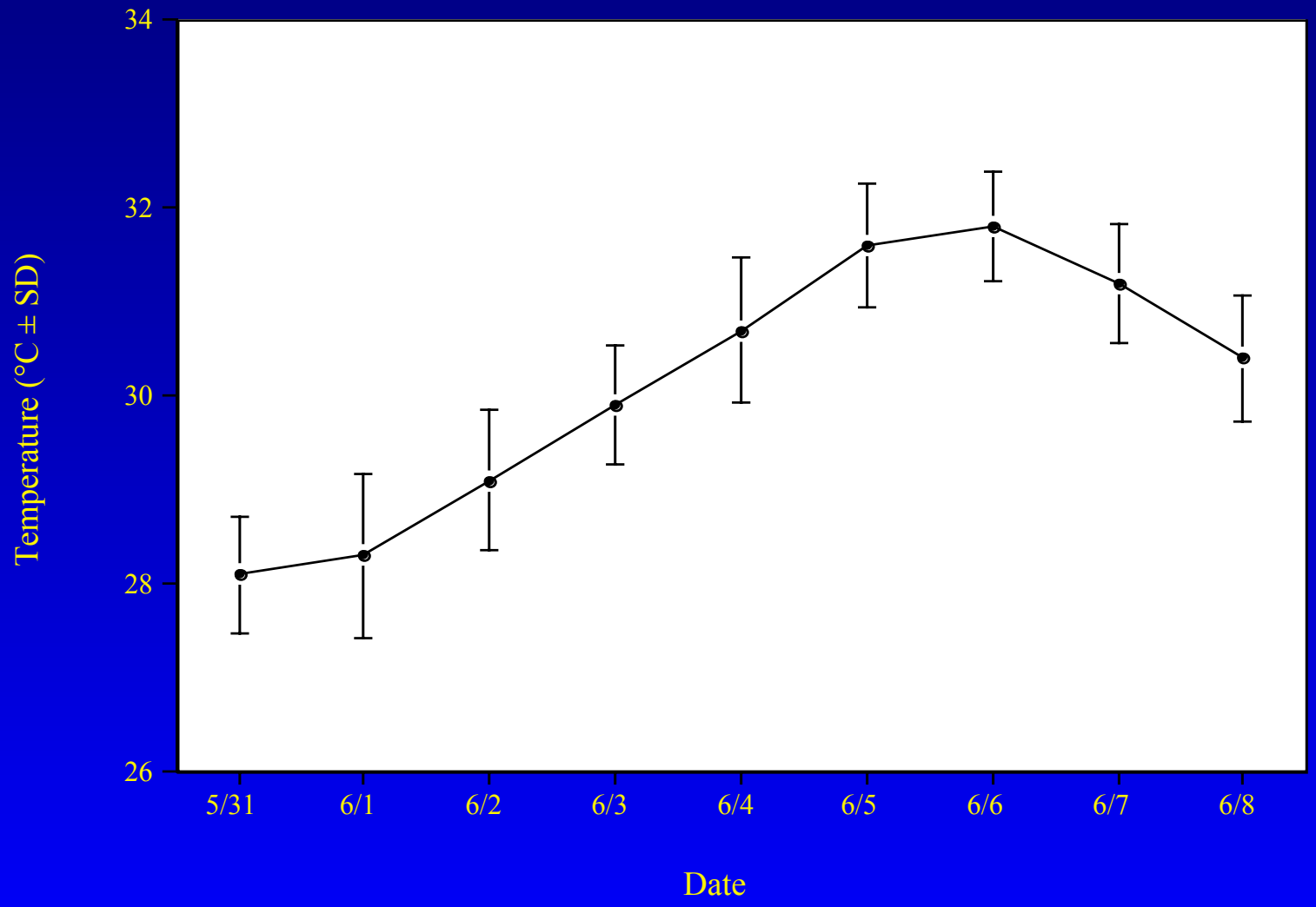
SOD

$2O_2^- + 2H^+ \rightarrow H_2O_2 + O_2$

Peroxidase/Catalase

$2H_2O_2 \rightarrow 2H_2O + O_2$

Thermal Stress



Parameters Measured by Active Fluorescence

- quantum yields of PSII chlorophyll fluorescence
- functional absorption cross section of PSII
- rate of electron transport through PSII
- energy transfer between photosynthetic units
- coefficients of photochemical and non-photochemical quenching
- parameters of photosynthesis versus irradiance (*P-I*) curve

Dynamic versus Chronic Photoinhibition

Dynamic Photoinhibition- a reversible regulatory phenomenon whereby excess "excitation pressure" is dissipated as heat or fluorescence, preventing oxidative stress, and photoinhibition of photosynthesis.

-xanthophyll cycle (diadinoxanthin/diatoxanthin)

-irradiance induced phosphorylation and migration of LHC II complexes away from PSII (State-1 to State-2 transitions)

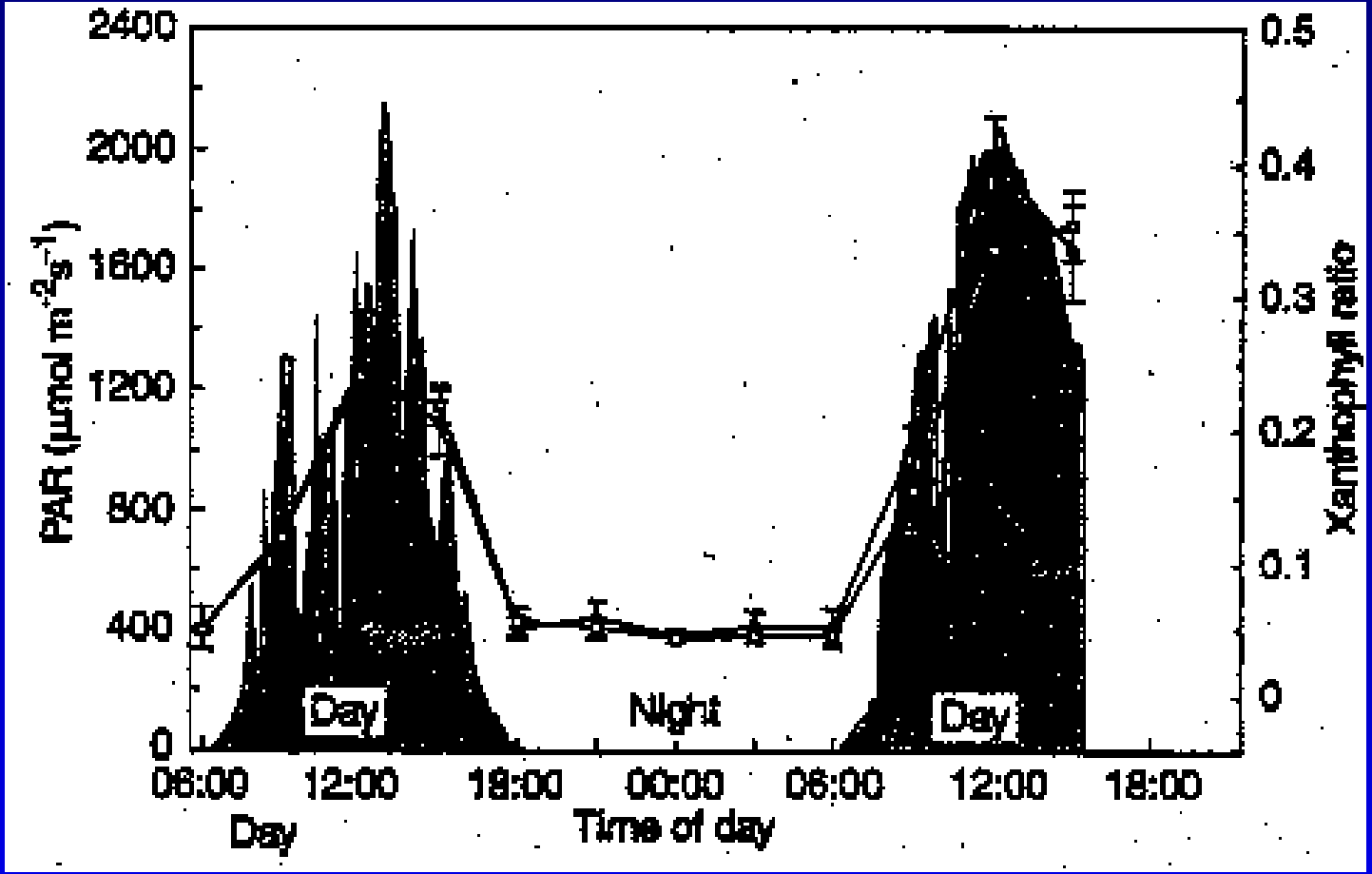
-enhanced thermal dissipation of PSII and down-regulation of photochemistry

Chronic Photoinhibition- irreversible damage to reaction centers of PSII after capacity of protective mechanisms has been exceeded.

-degradation of reaction center protein D1

-turnover of D1 protein can be hours to days depending on balance between damage and repair

Relationship Between NPQ and Xanthophyll Cycle



Brown et al. *1999* (*Coral Reefs,* 18:99-105)

Bleaching: Adaptive or Short-term Strategy?

Adaptive Bleaching Hypothesis vs. Short-term Strategy to Survive

Rates of bleaching unprecedented-faster than any geological evidence for past bleaching events and faster than zooxanthellae can adapt

What would make it more adaptive now than say even 50 years ago?

Most corals recover from most bleaching events

How "adaptive" is decrease in growth, loss of reproductive potential, and high mortality?

Habitats with restricted number of zooxanthellae genotypes